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Urban Heat Island of Jeddah

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ABSTRACT. The study includes meteorological measurements in the urban and rural areas of Jeddah. The characteristics of the *city heat island* and its diurnal variation is investigated. The maximum intensity was (2.8°C) at dawn and the minimum was (0.4°C) in early afternoon. The profile measurements over the city is used to define the dimension of the heat island. The early morning profiles show that the maximum height of this island was 100 m. This study could be useful for urban development and city design decisions.

Introduction

The urban areas are always warmer than the rural areas forming what is known as *urban heat island*. The temperature difference is called *heat island intensity*. The maximum intensity occurs at the time of minimum temperature. This phenomenon has been investigated at different locations around the world (Padmanbhamurty 1986, Chow 1986, Oke 1974, Sekiguti 1970, Landsberg 1970, 1981). The exact form and size of this phenomenon varies in time and space as a result of meteorological, locational and urban characteristics. The heat island was first expressed by Linke (1940). He pointed out that the town climate shows its greatest development in calm air and cloudless skies.

The urban heat island follows diurnal variation as well as seasonal variation (Jauregui 1986, Chow 1986, Padmanbhamurty 1986). The height of the heat island is determined from the base of the temperature inversion above the city. Usually, the heat island is capped by a stable air layer above (Oke 1978). The meteorological measurements taken inside and outside the city are useful tools to explain the urban microclimate of the city.

This study seeks the effect of human and industrial activities and the process of urbanization on the microclimate of Jeddah.

Material and Methods

The meteorological measurements for this study were taken from a project sponsored by King Abdulaziz University in 1986 and cover four seasons. In this paper, one day is selected as an example for winter season. During the whole period of the project, air temperature measurements were carried out three times a day on two days a month. Route measurements were made by a mobile station inside the city. At the same time, surface and upper air measurements were carried out in the University Campus. The routine meteorological measurements taken at the new airport (rural) station are also used. All the measurements are incorporated to describe the urban microclimate of Jeddah.

The structure of the city as it is located on the Red Sea and surrounded by the Sarawat mountains from the north-east, east and south-east dictates unique climatic features of the city. In this study the urban and rural areas are 11 m and 18 m above the mean sea level. No topographic effect is expected due to this height difference.

The analyses are made from the meteorological measurements taken on the *6th* of January 1986.

Instrumentation

The Mobile Station

It is a Range Rover with a mast fitted on its roof carrying a shelter at 3 m height above the ground. The shelter contains temperature and relative humidity sensors. These sensors are manufactured by Campbell Scientific, Inc., U.S.A. The car is used in a fixed route selected inside the city (Fig. 1). Representative sampling is achieved by traversing this route in two hour run. Average values are calculated for each stop. Three runs per day are confirmed as follows :

(1) Before sunrise (0400 – 0600 L.T.) when minimum air temperature is expected. At this time, maximum land breeze and urban heat island are expected to be in effect.

(2) Mid-noon (1400 – 1600 L.T.) when maximum air temperature is expected and consequently sea breeze.

(3) After sunset (1800 – 2000 L.T.) when town breeze is expected to be significant.

Air Temperature Sensors

The sensor used in the mobile station is a thermistor-hygristor probe. The sensor was calibrated before and after experiments and small difference averaging between 0.5-0.6°C in the range between 20-40°C are detected. The sensors used in the upper air station are with an accuracy of 0.1-0.2°C.

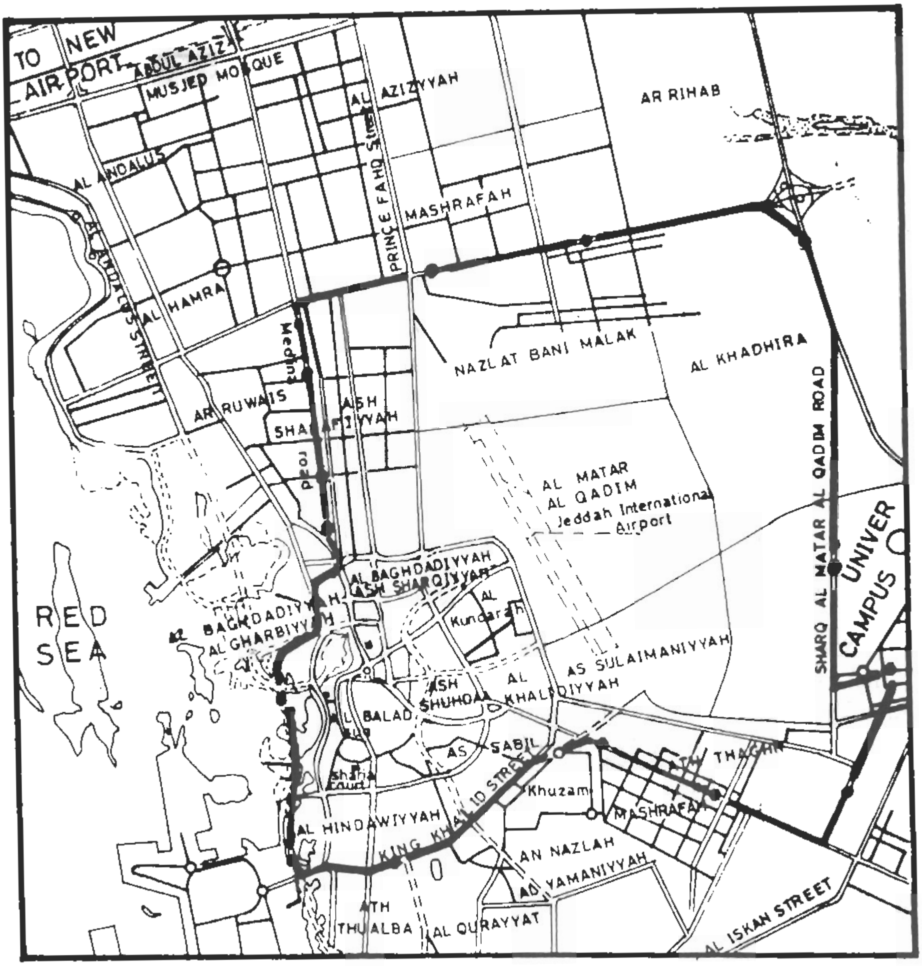

FIG. 1. A map for Jeddah city showing the route selected inside the city for the mobile station measurements.

Results and Discussion

In Jeddah city, there is a dense building area which is the centre of the city and another area which is an open area *Almatar Alqadim* where the old airport was located. In the vicinity of the centre of the urban area is the Red Sea. The rural area is the area of the New Airport.

Diurnal Variation of Heat Island Intensity

Table 1 shows average values of urban (route measurements) and rural (airport) temperatures at the three sampling times of the day (0500, 1500 and 1900 local times) on 6 January 1986.

TABLE 1. Temperature averages of urban ($\bar{T}_u$) and rural ($\bar{T}_r$) areas and the heat island intensities [$\Delta T_{(u-r)}$] for Jeddah at 0500, 1500 and 1900 L.T. on 6 January 1986.

	$\bar{T}_u$ °C	$\bar{T}_r$ °C	$\Delta T_{(u-r)}$ °C
Dawn (0500 L.T.)	22.8	20.0	2.8
Early afternoon (1500 L.T.)	30.1	30.0	0.1
Early evening (1900 L.T.)	26.1	24.0	2.1

The heat island follows a diurnal variation with maximum intensity at dawn (0500 L.T.). The minimum intensity occurs in early afternoon (1500 L.T.). It, then, rises again in the evening (1900 L.T.). The urban area is warmer than the rural area in the early morning and evening. There is almost no difference between them in the early afternoon.

The maximum heat island intensity $\Delta T_{(u-r)}$ for Jeddah on 6 January 1986 was 2.8°C at the time of minimum temperature. $\Delta T_{(u-r)}$ then rises again in the early evening reaching 2.1°C. The minimum heat island intensity was 0.1°C in the early afternoon at the time of maximum temperature.

It is noticed that early evening (1900 L.T.) $\Delta T_{(u-r)}$ values are positive. It is expected that the rural area is colder than the urban area as it emits longwave radiation rapidly. The energy stored in the buildings and narrow streets keeps the city warmer. The small values of $\Delta T_{(u-r)}$ during early afternoon may be due to:

(1) The effect of sea breeze which is most pronounced at this time of the day bringing fresh cool air to the city centre.

(2) The narrow and deep structure of the city canyon which is continually in shade. This means that the great absorption of net shortwave radiation is effective at the height of the buildings. Oke (1978) confirmed this point.

Heating and Cooling Centres

The distribution of heating and cooling centres inside Jeddah city is investigated. Fig. 2 shows the distribution of urban temperatures on 6 January 1986 at the three times of the day: a- (0500 L.T.), b- (1500 L.T.) and c- (1900 L.T.).

The early morning map (a) shows a hot centre existing in the area of dense buildings in Madinah road while a cold centre existing in the open area of Almatar Al-qadim. The picture is reversed in the early afternoon (b). The cold centre near the coast line in Madinah road is a result of sea breeze circulation. In the evening (c), the situation is a continuation of the afternoon picture but the isotherms observed show less gradient than those at early afternoon.

The hot centre in the early morning (Fig. 2a) is 23.4°C, in the early afternoon (Fig. 2b) is 31.6°C and in the evening (Fig. 2c) is 26.4°C, while the temperatures of the cold centres are 22.0°C, 29.2°C and 26.0°C respectively.

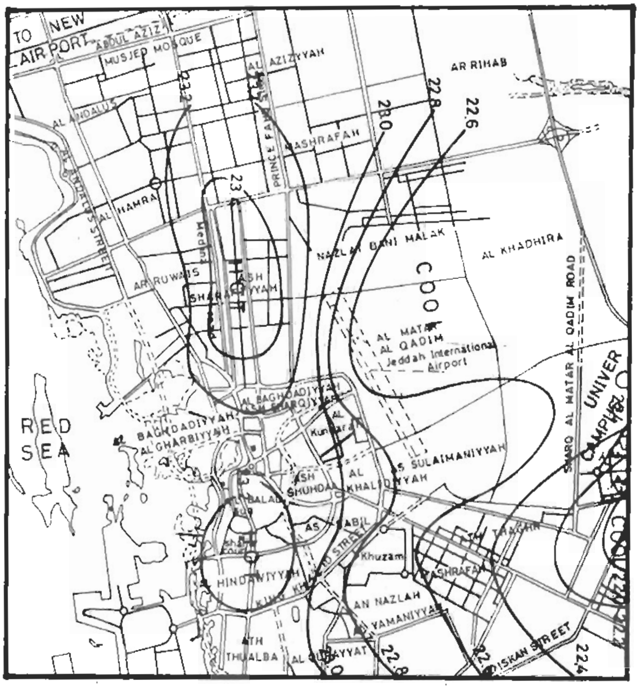

Fig. 2 (a) Distribution of heating and cooling centres in Jeddah at (0400 – 0600 L.T.) on (6 Jan. 1986).

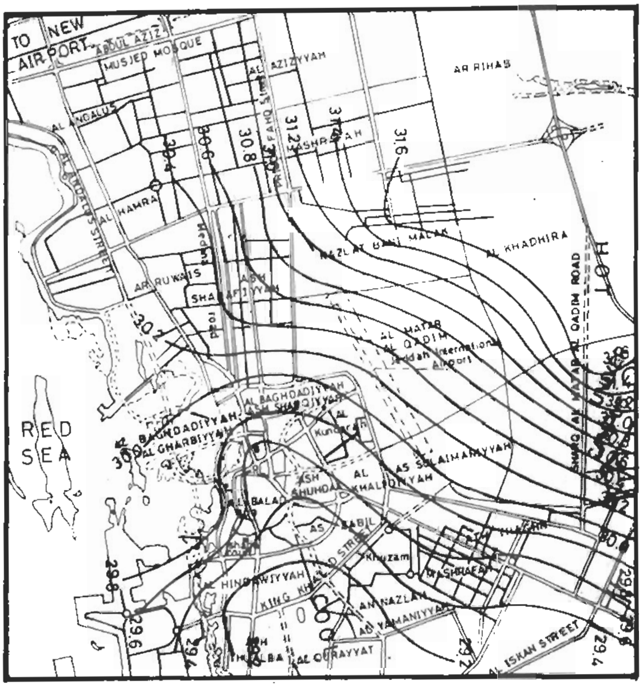

Fig. 2 (b) Distribution of heating and cooling centres in Jeddah at (1400 – 1600 L.T.) on (6 Jan. 1986).

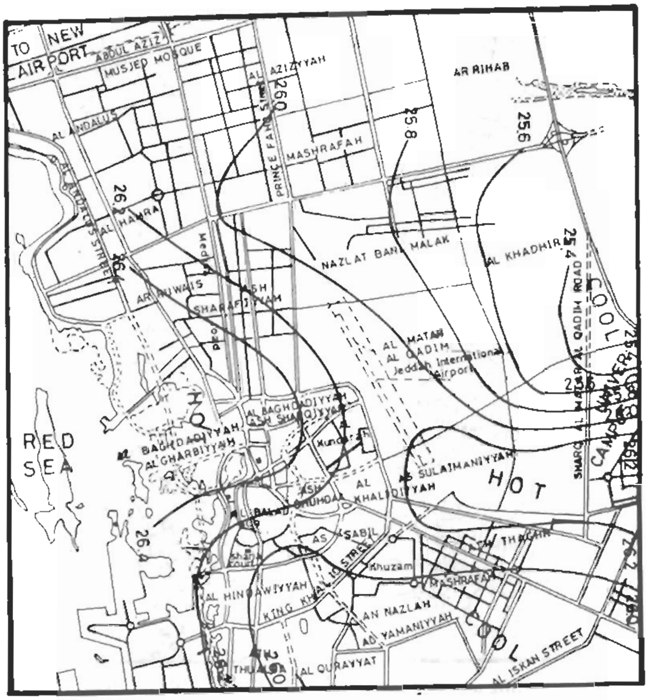

FIG. 2. Heating and cooling centres inside Jeddah on 6 January 1986; a – Early morning, b – Early afternnon, c – Early evening.

The differential heating in the morning, in the afternoon, and in the evening are 1.4°C, 2.4°C, and 0.4°C, respectively.

Vertical Structure of Air Temperature

The vertical profiles of temperature up to 1 km height over the city of Jeddah are investigated using the soundings of the upper air station at the university site. Measurements were carried out three times a day, early morning (0400 – 0600 L.T.), early afternoon (1400 – 1600) L.T.) and early evening (1800 – 2000 L.T.). The data are selected for the same investigated day in winter (6 January 1986). Figure 3 shows the results on this day. The early morning profile shows nocturnal inversion on the rural area of the new Jeddah airport (dotted line). The inversion is based at the ground. The night was characterized by clear skies and calm winds up to a height of 40 m.

Figure 3 shows a situation of advection of stable rural air across urban area before sunrise. The lower part of the urban temperature profile curve indicates a weak lapse rate in the urban boundary layer surmounted by the remnants of an upwind rural radiational inversion. This inversion appears at 100 m height above the surface indicating the contraction of the urban heat island to this height. In this case, any vertical transfer process is expected to be very much suppressed.

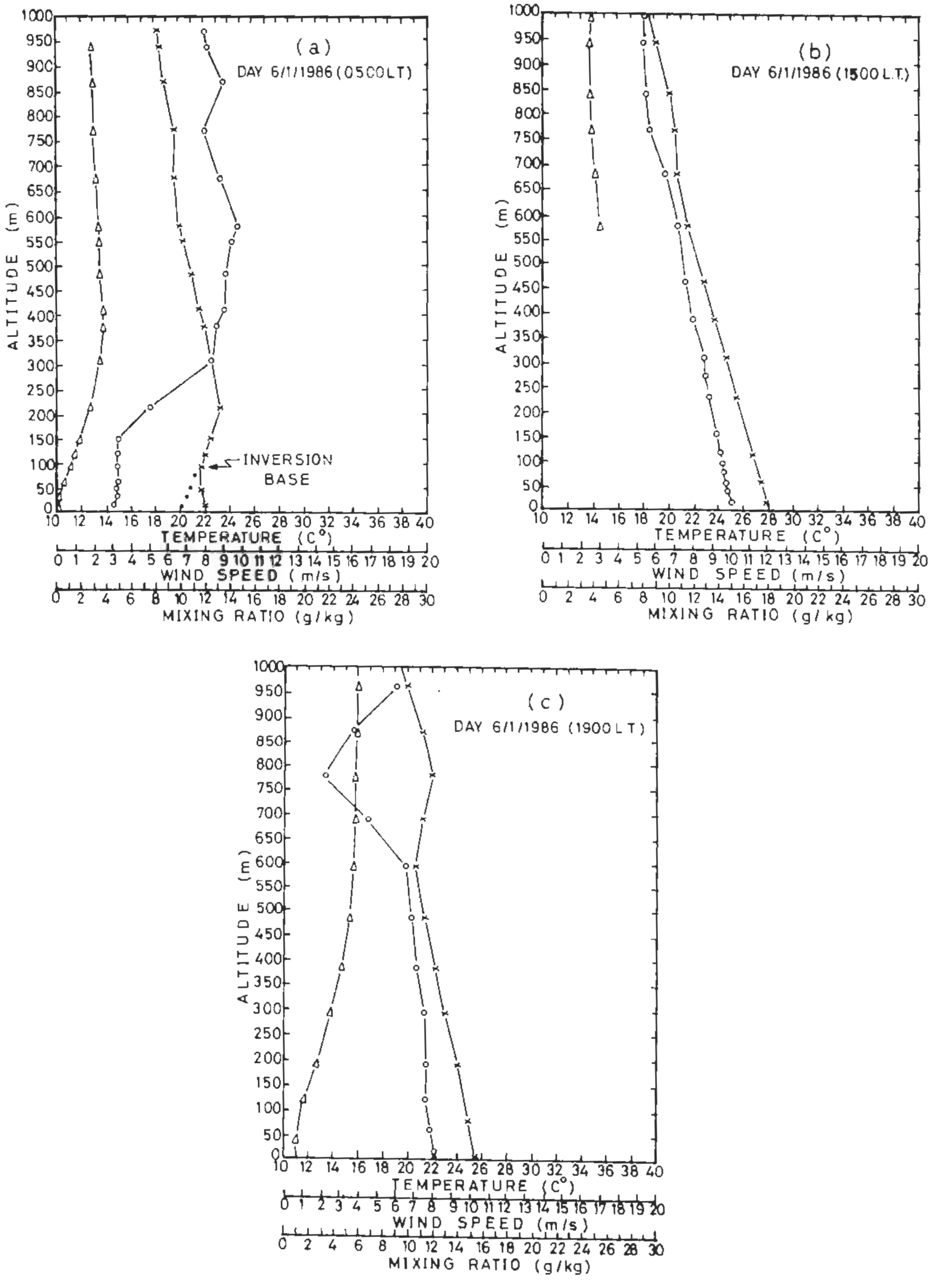

FIG. 3. Temperature (x), humidity (o) and wind speed (Δ) profile measurements up to 1 km height above the city of Jeddah at three times: (a) dawn (0400 – 0600 L.T.), (b) afternoon (1400 – 1600 L.T.), and (c) evening (1800 – 2000 L.T.).

At the rural area of the new Jeddah airport, the surface temperature was 20°C and the profile shows a rural inversion based at ground and extends up to 200 m. Across the urban boundary, the surface temperature rises by 3.5°C at the centre of the city heat island. As the rural air crosses the urban boundary, the height of the heat island is determined by the rural-urban temperature difference (see Fig. 3a). The wind profile in this figure shows wind speed of 1 m/s at the top of heat island.

From the above discussion, it can be concluded that the early morning temperature and humidity profiles can be used to quantify the size of the urban heat island. The early afternoon temperature profile shows lapse condition capped by an inversion based at 700 m. Afternoon turbulent mixing is expected as a result of maximum heating of the surface at this time of the day. As a result, the surface inversion is broken down near the surface leaving upper remnants at about 700 m height. The early morning humidity profile shows an increase with height. Water vapor is advected from the sea side. In the early afternoon, turbulent mixing takes place and the humidity is decreased with height (Fig. 3b). This situation may be continued till the evening. The evening temperature (Fig. 3c) can be used to quantify the intensity of the next morning inversion.

Conclusion

It was possible to investigate some of the main features of the urban microclimate of Jeddah from the meteorological measurements taken inside the city and in the rural area of the airport during a sample day in winter.

The structure of the city and its location on the Red Sea surrounded by mountains from the northeast, east and southeast dictates unique urban microclimatic features. The study also seeks the effect of human and industrial activities and the processes of urbanization on the microclimate of Jeddah.

The map of heating and cooling centers show that a hot center exists in the area of dense building in the city center and Madinah road while a cool center exists in the open area of *Almatar Alqadim* at the time of maximum heat island intensity early in the morning. The picture is reversed in the early afternoon as the area of dense building in the city center is affected by sea breeze.

The maximum heat island intensity is observed at dawn (0500 L.T.) and the minimum early afternoon (1500 L.T.) These results agree with the reported results for different coastal cities in semi arid and arid regions of the world. The early morning temperature and humidity profiles are used to quantify the size of the *city heat island* (Fig. 3a).

The early afternoon profiles show that the urban boundary layer is capped by an inversion. After sunrise, when the surface is heated, turbulent mixing takes place and breaks the early morning inversion. The inversion appeared to be lifted to a height of about 700 m. As a result of this air mixing the humidity profiles show a slight decrease in the water vapour content with height (Fig. 3b).

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الجـــزيرة الحراريـــة لمدينـــة جـــدة

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المستخلص . تشمـل هذه الـدراسة قياس العناصر الجوية داخل وخارج مدينة جدة ، بهدف تحديد خواص الجزيرة الحرارية للمدينة وتغيرها اليومي . أوضحت قياسات التغير الرأسي للحرارة والرطوبة والرياح فوق المدينة أبعاد هذه الجزيرة الحرارية .

يمكن الاستفادة من نتائج هذه الدراسة في التخطيط للتوسع العمراني واتخاذ قرارات التصميم للمنشآت داخل المدينة .